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Normalized vertical ice mass flux profiles from vertically pointing 8-mm-wavelength Doppler radar

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I. Introduction

During the FIRE II project, NOAA's Wave Propagation Laboratory (WPL) operated its 8-mm-wavelength Doppler radar extensively in the vertically pointing mode. This allowed for the calculation of a number of important cirrus cloud parameters, including cloud boundary statistics (Uttal and Intrieri, 1993), cloud particle characteristic sizes and concentrations, and ice mass content (*imc*) (Matrosov et. al. 1992; 1993). The flux of *imc*, or, alternatively, ice mass flux (*imf*), is also an important parameter of a cirrus cloud system. Ice mass flux is important in the vertical redistribution of water substance and thus, in part, determines the cloud evolution.

It is important for the development of cloud parameterizations to be able to define the essential physical characteristics of large populations of clouds in the simplest possible way. One method would be to normalize profiles of observed cloud properties, such as those mentioned above, in ways similar to those used in the convective boundary layer. The height then scales from 0.0 at cloud base to 1.0 at cloud top, and the measured cloud parameter scales by its maximum value so that all normalized profiles have 1.0 as their maximum value. The goal is that there will be a "universal" shape to profiles of the normalized data.

We have applied this idea to estimates of *imf* calculated from data obtained by the WPL cloud radar during FIRE II. Other quantities such as median particle diameter, concentration, and ice mass content can also be estimated with this radar, and we expect to also examine normalized profiles of these quantities in time for the 1993 FIRE II meeting.

II. Methodology

Using the empirical relationship of Sassen (1987), it is possible to estimate *imc* from 8-mm radar reflectivity. Multiplying this *imc* by the Doppler velocity produces an estimate of *imf*. This calculation was performed on a beam-by-beam basis and then averaged for 25 min (during every half hour the radar was operated 25 min in the vertically pointing mode). Calculations of *imf* have been performed for a number of intervals from 22, 25, 26, and 28 November 1991 during FIRE II.

Since cloud top and base will fluctuate, sometimes considerably over a given averaging period, it was necessary to impose certain thresholding criteria. First, at least 300 beams out of a possible 480 during a 25 min averaging period were required to have "good data". This "good data" classification was considered conservative and applied separately to the velocity and reflectivity data fields before the calculation of *imf* was performed and included considerations of signal strength, and pulse to pulse correlations of returned power.

Secondly, since the relationship of Sassen (1987) is an empirical relationship for ice clouds, it was necessary to eliminate cases which might have significant liquid water content. A value of -20°C was chosen as a threshold value; any cloud that had an average base temperature warmer than -20°C was eliminated from the analysis. This ensured to a reasonable degree that the radar was observing ice clouds. After the above thresholding had been applied, the data were normalized as described and plotted separately for each day.

III. Results and Discussion

The plots in Figs. 1-3 summarize the results from 25, 26, and 28 November. A total of 18 hrs of data were examined from these three days with 9 hrs passing the thresholding criteria. The times noted in the legend are in GMT and are the start of each 25 min averaging period. The vertical scale is normalized cloud depth as defined by the radar after all thresholding tests were applied. The darker line is an eighth degree polynomial fit that is presented to outline the general shape of the normalized data. No attempt is made in this study to derive a general equation for all three data sets, however, this will be addressed in future analysis.

Plots of the three cases shown in Figs. 1-3 have a number of similarities. First, there are relatively low values at cloud top and base with a distinct peak near the bottom of the cloud. The mean, normalized flux at cloud top approaches zero and ranges from 0.3 to 0.5 at cloud base. The data from 25 November has a peak flux at a normalizedheight of 0.3, 26 November has a peak just above 0.1, and the peak is at 0.2 for 28 November. On 26 November, the peak in *imf* at a rather low level within the cloud may be partly the result of requiring a 300-beam minimum for good averages.

Cloud base on 26 November was slowly decreasing, even over the 25 min averaging period. The thresholding scheme may therefore haveeliminated the lower portion of the cloud. Cloud base on 25 and 28 November was much more stable over a given averaging period. Plotting the 26 November data without this thresholding produces a peak closer to 0.2.

A fourth day (not shown) was 22 November, which was not plotted because cloud base temperatures were much warmer than the -20°C threshold. Nevertheless, the normalized profiles from this day were very similar to those shown here, with a peak flux just below the 0.3 level.

We point out here that the relationship of Sassen (1987) is empirical and can be expected to be most accurate for the microphysical conditions under which it was obtained. New, more general techniques are being tested to derived *imc* and *imf* (Matrosov, et al., 1993). These incorporate radar reflectivity, Doppler velocity, and infrared radiometer data sets, and should improve the *imf* calculation.

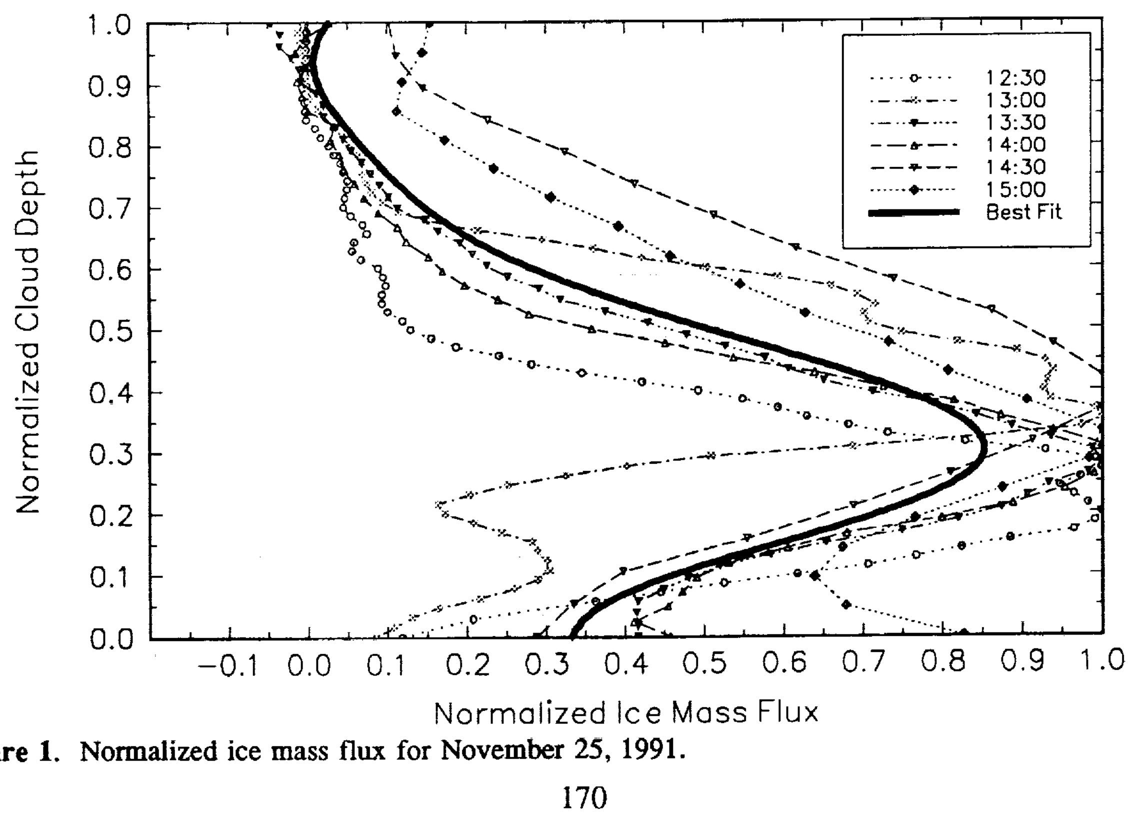

Figure 1. Normalized ice mass flux for November 25, 1991.

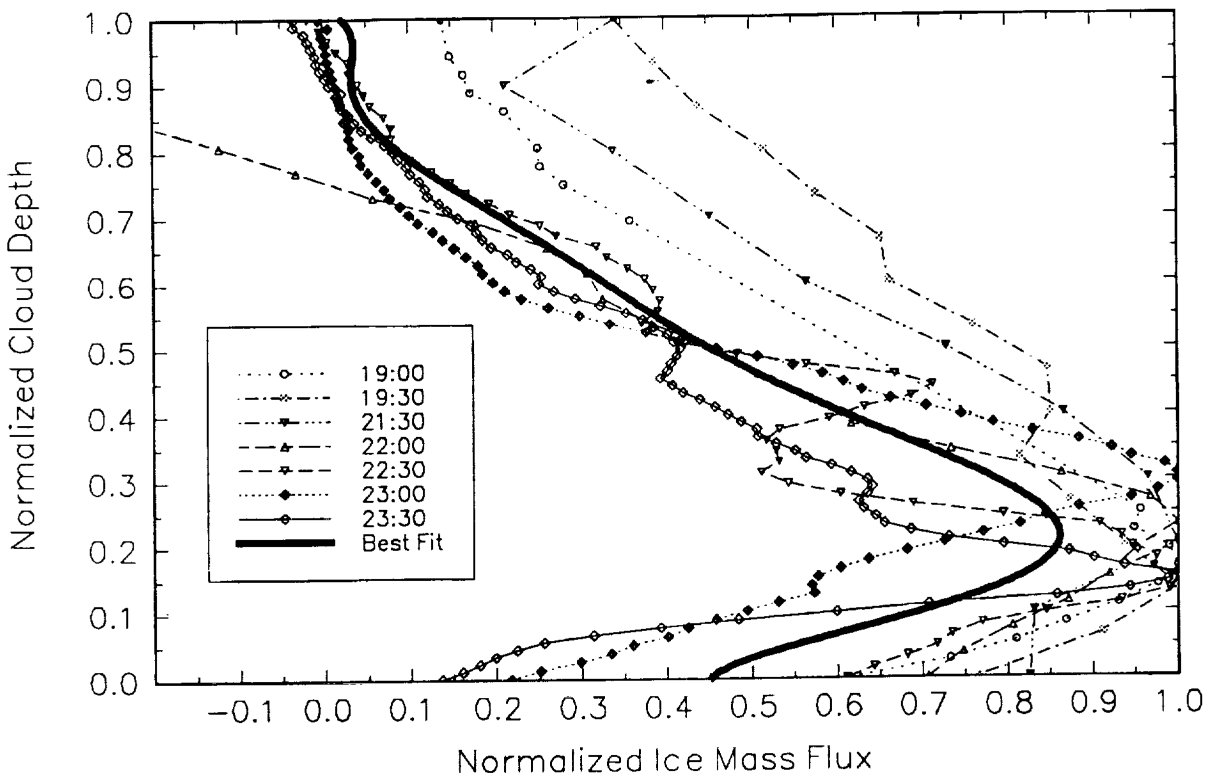

Figure 2. Normalized ice mass flux for November 28, 1991.

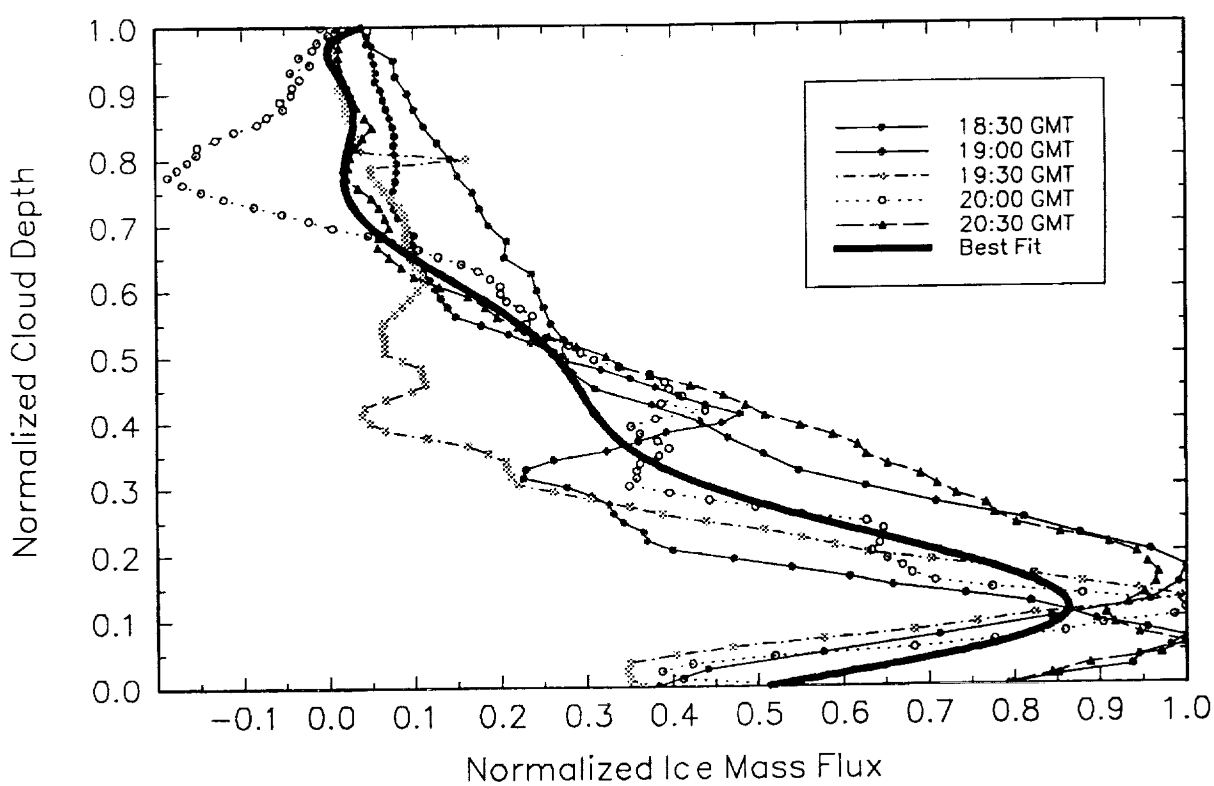

Figure 3 Normalized ice mass flux for November 26, 1991.

IV. Summary and Conclusions

The similarity of the three normalized *imf* data sets is encouraging. This description of cirrus clouds, if it proves generally applicable, could be valuable in improving the parameterization of cirrus clouds in GCMs. Modifications of this technique are being considered to determine better and simpler ways of characterizing cirrus clouds. Data sets from different locales, such as Porto Santo Island, Portugal, and Boulder, Colorado, will also be analyzed (using this technique) to determine the generality of these results.

V. References

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